Internal Combustion Engine
- without cooling

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We treat exclusively internal combustion engines (ICEs) with liquid or solid fuel injection.

In an ICE, all cooling is waste of useful work.
There are three main sources of heat wasting:

1 - Compression intake volume too big
2 - Excessive compression
3 - Residual heat from exhaust gases

There are no thermodynamic issues since, at ambiant temperature and pressure, entropy of reaction products is always superior to entropy of reaction input (educts).

ad 1 - compression intake volume too big

For reasons unknown, one has the habit of taking the entire cylinder volume as the starting volume for compression.
When the gas is heated through fuel burning, the product gases, once expanded back to the original volume, will have considerably higher temperature and higher pressure than at the intake.
This is immediately clear since doing nothing to the compressed gases would just bring them back to the original state.
The remedy is to simply compress a volume smaller than the expansion volume such that pressure at maximum expansion equals ambient pressure (p_0).
This way, no pressure work is lost.
We might reckon that this is already the bulk of cooling and certainly the major source of noise.

ad 2 - excessive compression

An adiabatic compression of ratio three is enough to bring a gas from room temperature (≈300K) to more than 1000K (≈700°C), more than enough if one has ignition concerns.
A compression of a factor twenty would get us to more than 6000K, hotter than the sun.
All of this excess heat goes into the cast through heat conduction and is lost as useful work.
Therefore, one keeps the cylinder and piston as thermally isolated as possible and compresses only to useful temperatures.

ad 3 - Residual heat from exhaust gases

This is the only heat loss that is theoretically acceptable, once the previous issues taken care of.
Since we cannot avoid this heat, all we can do is recover it.
We do this by heating up the incoming liquid fuel.
This is being done by counterstream heat exchange where several successive strokes are gradually being heated by the outstreaming exhaust gases.
This method allows, in principle, to heat up the incoming fuel to exhaust temperature T_{exh} and to cool the exhaust gases from T_{exh} to external temperature T_0 .
See figure 2

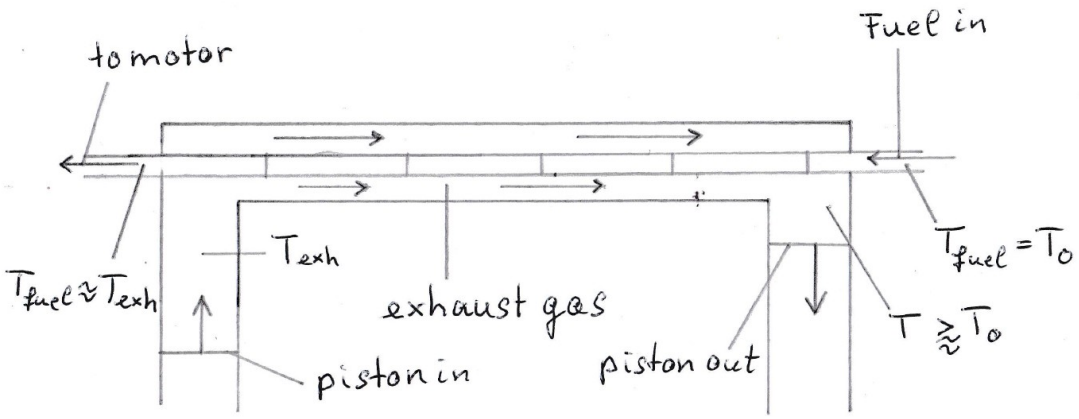

fig. 2 Exhaust gas is isochorically (same volume) displaced along incoming fuel. One pushes in at the left and pulls out at the right. This way, no outside work is done on exhaust gas.

Conditions of Heat Recovery

The total heat quantity that can be absorbed by the incoming liquid fuel is given by

$Q_F = c_V(\text{fuel})(T_{exh} - T_0)$

where c_V(fuel) is the (molar) heat capacity of the liquid fuel which one assumes constant at the temperatures involved.

The exhaust heat available is

$Q_H = c_V(\text{exhaust})(T_{exh} - T_0)$

where c_V(exhaust) is the heat capacity of the exhaust gases for one mol of liquid fuel which one assumes, once again, constant at the temperatures involved.

Hence, the ratio of recoverable exhaust gas heat (a) is simply

$a = Q_F / Q_H = c_V(\text{fuel}) / c_V(\text{exhaust})$

if $a > 1$, we can recover all exhaust heat by preheating the liquid fuel.

Let us now look how much heat can be recovered for various cases.

- *carbon and oxygen*

Burning carbon and oxygen gives carbon dioxide

$C + O_2 \rightarrow CO_2$

Usually $c_V(\text{carbon}) > c_V(CO_2)$, hence $a > 1$ and we can recover all exhaust heat.

- *oil and oxygen*

Oil can be viewed as chains of CH_2 units. Burning them gives carbondioxyde and water vapour

$2CH_2 + 3O_2 \rightarrow 2CO_2 + 2H_2O$

Here $c_V(2CH_2) \approx c_V(2CO_2 + 2H_2O)$, so we are at the limit of total heat recovery.

- *oil and air*

World is not perfect. We do never burn pure oxygen but always air, hence a 4:1 mixture of nitrogen and oxygen.
This gives for our molar quantities

$2CH_2 + 3O_2 + 12N_2 \rightarrow 2CO_2 + 2H_2O + 12N_2$

Now $c_V(2CH_2) < c_V(2CO_2 + 2H_2O + 12N_2)$, hence $a < 1$ and heat recovery will only be partially possible, 30% being a realistic number.

energy recovery

On top of heat recovery, one can always recover useful work from the outside world.
Suppose that we cooled the exhaust gases at constant volume down to ambient temperature T_0 .
At initial exhaust temperature T_{exh} and initial expansion volume V_{exp} , exhaust gas pressure was outside pressure p_0 (see ad-1above).
At the now lower temperature, exhaust gas pressure will have dropped below external pressure.
Hence, the external atmosphere can do work on the piston by moving it in (see fig. 3).
We can keep exhaust gas temperature constant at T_0 by continuous cooling.
The volume work recovered is given by

$$W = \int dV(p_0 - p(exh))$$

The exhaust gases will be isothermally compressed until their pressure equals outside pressure.

The energy cooled away equals the work obtained.

If we treat all gases as ideal, the work obtained is given by

$$W = p_0 V_{exp}\{1 - (T_0/T_{exh})(1 + \ln(T_{exh}/T_0))\}$$

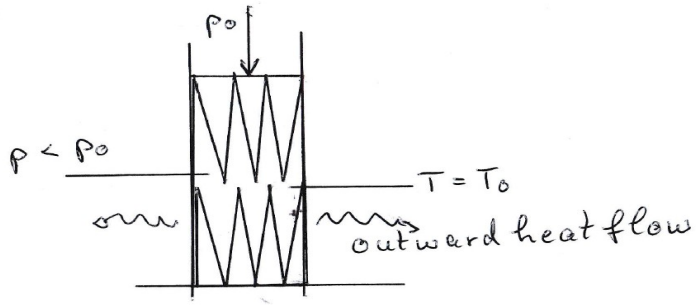

fig. 3 cooled exhaust gas is transferred to a cylinder with great internal surface to maximise cooling efficiency. This is indicated as lamellaes (spikes). During compression, cooling keeps gas temperature constant.

Diesel - Fuel Cell Engine

The promised ICE without cooling turned out to not be entirely feasible in the real world.
Let us try another variant.
As liquid fuel we will take oil and water and burn it to carbondioxyde and hydrogen

$CH_2 + 2H_2O \rightarrow CO_2 + 3H_2$

As $c_V(\text{fuel}) > c_V(\text{exhaust})$, we can recover all of the exhaust heat.

What about our hydrogen? Burning it with air will throw up the same problems as before.
Instead, we will not burn it at all but separate it from carbondioxyde and feed it into a *fuel cell*.

$2H_2 + O_2 \rightarrow 2H_2O$

This gives a hybrid Diesel-Fuel-Cell Engine (DFC engine) which has, therefore, a theoretical efficiency of 100%.

The total chain is

$CH_2 + 2H_2O \rightarrow CO_2 + 3H_2 + (3/2)O_2 \rightarrow CO_2 + 3H_2O$

The initial water is recovered at the end. It serves as a *catalyst* making this process suitable for engines in transportation (cars, trucks, locomotives)

Ecological Consequences

The highly efficient DFC engine makes this the *ideal power plant.* One does not wish to run it with conventional reciprocating pistons but will rather use *circular pistons*. That is a trivial idea, already pondered by James Watt. See figure 4 for its functioning.

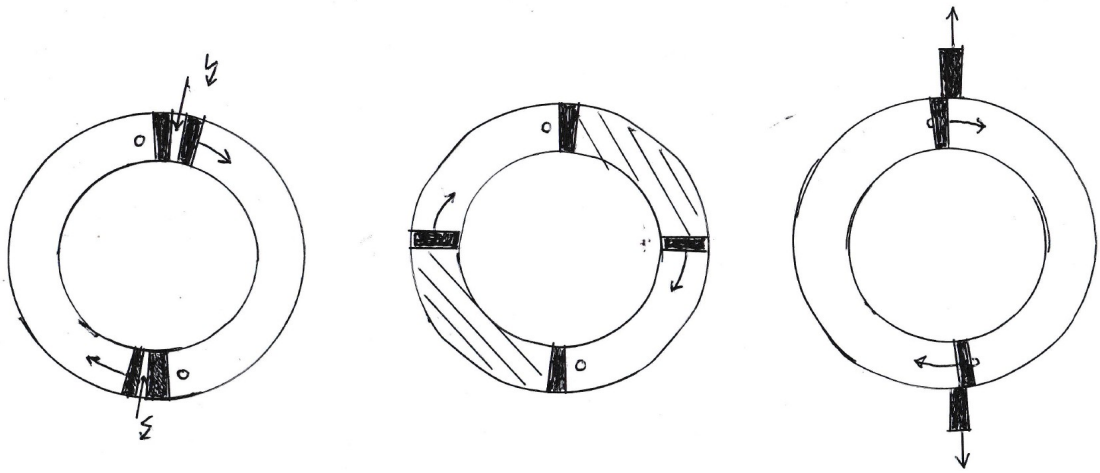

fig. 4 circular piston. Consists of fixed side walls and outer perimeter. Inner perimeter is moving with piston bottom attached. Cylinder top is fixed but retractable. Left: liquid fuel injection and ignition. Middle: expansion / exhaust of previous stroke. Right: Retraction of piston top and passage of piston bottom. After that, go back to 1st step.

The DFC engine makes *Oil* the *ideal combustible*.

Most fossile reserves are in coal but coal can only be used efficiently in oversized thermal power plants with lots of waste heat and efficiencies of around 30%.
Liquefying coal (Kohleverflüssigung) already practiced by the Germans during WWII is a way of boosting coal efficiency to 100%, decentralized, in small adapted powerplants.

The basic liquefaction process uses coal and water according to

$$2C + 2H_2O \rightarrow 2CH_2 + O_2 .$$

Oil also becomes the *ideal energy storage medium* for renewable energy sources (wind, water, sun)
The basic process is to use carbondioxide and water according to

$$2CO_2 + 2H_2O \rightarrow 2CH_2 + 3O_2 .$$

In the case of stationary DFC-power plants, one can recover the carbon dioxide directly and cool it down by a heat pump to liquid temperatures (-50°C). The heat gained can be used as house heating or process heat.
Liquid carbondioxide is bottled up and put at the disposal of oil regeneration facilities.
A possible simple electrolytical regeneration scheme, that might actually work with suitable catalysts is shown in figure 5.

Both processes, coal liquefaction and oil regeneration, give off oxygen which can be directed to sites of energy consumption or places where one wants to improve air quality.

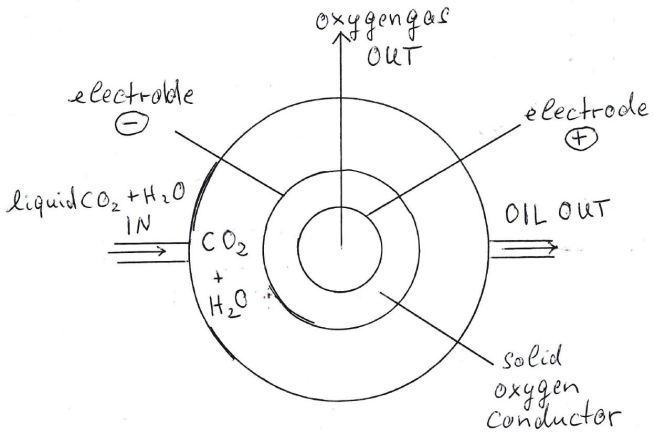

fig. 5 Oil regeneration: liquid carbondioxyde and water are injected at high pressure. The negative electrode of a voltage generator gives electrons off to oxygen which migrates across a solid oxygen conductor to the outside positive pole and vents out at ambient pressure.